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**Citation for published version:**

Kranioti, E 2016, 'PMCT investigation of mummified forensic evidence from medieval Germany', *Journal of Forensic Radiology and Imaging*, vol. 6, pp. 14-20. <https://doi.org/10.1016/j.jofri.2016.08.001>

**Digital Object Identifier (DOI):**

[10.1016/j.jofri.2016.08.001](https://doi.org/10.1016/j.jofri.2016.08.001)

**Link:**

[Link to publication record in Edinburgh Research Explorer](#)

**Document Version:**

Peer reviewed version

**Published In:**

Journal of Forensic Radiology and Imaging

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Original article

**PMCT investigation of mummified forensic evidence from medieval Germany**

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## Abstract

**Objectives:** to estimate the sex of a set of mummified right hands from in Medieval Germany with the aid of non-invasive Computed Tomography in an effort to shed light on these people's identities. These hands were initially thought to have belonged to thieves, robbers or impertinent children that were punished by amputation. Recent research identified them in the literature as "*Leibzeichen*", body parts of unknown individuals murdered in the late Middle Ages that represented the dead person in court.

**Material and Methods:** The dimensions of the metacarpal bones are used as a proxy for size differences between males and females. CT scans were used to obtain the measurements. Four different population-specific equations from the literature were employed and a control sample of modern anatomical specimens and hospital patients' records from Germany were used to validate the equations.

**Results:** Five hands were classified as probable male (Münster, Erkeln, HWI 2641, Legden, Lunow), one as probable female (Goslar) and one was inconclusive (HWI 4019).

**Conclusion:** An approximation of sex for the mummified hands under study was possible using PMCT technology. Further DNA analysis must be conducted to verify or reject the preliminary results of morphometric sex assessment for these historical remains.

**Keywords:** Virtual anthropology; PMCT; mummified hands; sex estimation; metacarpals; hand bones; Leibzeichen

## INTRODUCTION

Mummified hands were found separated from their bodies in Germany, mostly in cities, which once belonged to the medieval union of the Hanse, like Goslar, Münster, or Wismar. Such mummified hands were discovered in secret niches of churches and castles; some are exhibited in museums as valuable relics while others are carelessly discarded. Naturally, questions concerning the reason for such dismemberment troubles both the public and scientists. Information on these hands mostly derives from local traditions, legends, or ordinary rumors and is thus of limited value.

Local traditions often want these hands to belong to famous aristocrats or heroes who died in battle. Very common widespread tales want the hands to belong to children who raised a hand against their parents and thus were punished by losing their own. This is also mentioned in the Code of Hammurabi, a set of laws in Mesopotamia (today's Iraq): *If a son strikes his father, his hands shall be hewn off* (Code of law 195) [1]. A third explanation suggests that such a hand is a sign of corporal punishment of thieves. Indeed in Sharia, Islamic law, and in Medieval Europe a thief should be penalized either by imprisonment or dismemberment of hands or feet [2], depending on the frequency and severity of the crime. According to other sources, however, the punishment for theft in Medieval Europe was usually hanging or, if the suspect was a female, the penalty could be drowning or burying the person alive [3]. Corporal amputation was also known in the Germanic Law of the "*Sachsenspiegel*" (Saxon mirror) of the early 13<sup>th</sup> century [4]. One could lose a hand when found guilty of oath breaking, counterfeiting or violence if not able to compensate with a specific amount of money (*wergeld*).

According to recent studies by the archaeologist Peter Pieper [5, 6] these mummified hands represented dead persons in court. In early times, the corpse of a homicide case was brought before the court as a *corpus delicti* to raise a complaint (*klage mit dem toten mann*). Naturally, when legal proceedings were lengthy, or the guilty person could not be identified immediately, decomposition could advance

significantly and the deceased had to be eventually buried. Therefore, a so-called "*Leibzeichen*" [6] was retained as a piece of evidence, representing the victim during the trial. Such a mummified hand is likely to be a substitute of the dead person who did not find justice in the past and remained as evidence in the archives. Several records describe the use of a hand, later a finger, or even a piece of bloody clothing, representing a dead person in court [5, 6].

Some of these hands were investigated in the Department of Archaeology, at the Heinrich Heine University in Düsseldorf, Germany during the last decade. They are body parts of unknown individuals who lived some centuries ago. Due to their special nature they are without a doubt of historical significance. The purpose of this study is to identify the sex of seven mummified hands that are thought to have lived between the 15<sup>th</sup> and 18<sup>th</sup> century in Germany in order to give more information about their social significance. With respect to the preservation of these historical relics a non-invasive technique was applied so that preservation of the remains could be secured. In this regard, CT scanning was determined to be most appropriate method, allowing a more detailed inspection of the hands' morphology and potential pathology.

To date no study reports sex estimation standards for the German population based on hand bone measurements, thus, four published studies of sex estimation using metacarpal measurements of different European samples [7-10] were used to assess sex. The suitability of these osteometric methods for the virtual metacarpal bones from the mummified hands and the validity of methods developed from different populations was assessed using a control sample of German descent.

## MATERIALS AND METHODS

The study sample consists of 19 individuals divided in 3 groups.

**Group 1 (G1):** Seven right mummified hands of unknown sex, stature and age that were found in different regions of Germany. Each of these hands was classified as

Leibzeichen by the archaeologist Peter Pieper who conducted the morphological analysis [6] and they are described in brief below.

*Münster Hand* (*Abgeschlagene Hand*): This hand is exhibited in the old City Hall Museum of Münster, Germany, placed in a small oak box. The box dates from the second half of the 16<sup>th</sup> century, but the hand itself is believed to be earlier. The museum catalogue has a reference to a hand of a forger [11]. Nevertheless, the hand is seemingly carefully dissected from the wrist while the carpal bones remained intact. All distal phalanges, 4<sup>th</sup> and 5<sup>th</sup> medial phalanges and the 5<sup>th</sup> proximal phalanx were missing, most likely decayed with time.

*Erkeln Hand*: It was found inside a secret niche of a wall in an old church in Erkeln [12]. A wall was built up after the dissection very likely to keep the relic hand out of sight. The hand is complete, displays no obvious pathology and is small and finely shaped suggesting that it had not been used in manual labor. It was cut with a sharp object recognized by smooth surface of the distal ends of the radius and ulna.



**Figure 1. 3D reconstructions of the Erkeln Hand using CT images. Image credit: Dr. Pieter Pieper.**

*Wismar hands*: Two hands along with two wooden plates were given to the Wismar 'Schabbelhause' Museum in 1898. They were carefully separated from the rest of the body and identified as Leibzeichen [6]. CT scanning did not reveal any obvious

signs of trauma or pathology. The first hand (HWI 2640 KO) seems more robust, but incomplete with the thumb missing. The maximum length, measured from the wrist to the distal end of the third distal phalanx, is 14.9 cm and the weight 76.1 g. The second (HWI 4019 KO) is complete, unarticulated as well and weighed 93.8 g. The maximum length is estimated to be 13.5 cm.

*Goslar Hand*: mummified right hand, delivered to the Goslar Museum in 1905. Rumours suggest that it belonged to a female but this could not be confirmed through the archival records. First digit is absent, very likely decayed through time, but not removed surgically. It was cut professionally with a special instrument revealing the surface of both os triquetrum and scaphoideum of the wrist [6].

*Legden Hand (perjury-hand)*: this mummified hand was stored in a wooden box inside the old St. Brigida Church (Figure 2). It was discovered preserved in lime during the demolition of an old fortified town in 1905. It is thought to have belonged to a young aristocrat who was murdered. Other legends suggest that it belonged to someone that broke an oath, and it was cut to serve as a bloody lesson to anybody else contemplating straying from the truth. Yet, nobody knows the real history behind the hand and no archival information was available. In 2012 the hand was stolen from the church [13] but luckily morphological and virtual examination through CT scans were performed previously. The hand is complete and carefully dissected. All carpal bones are intact and undamaged [6]. This suggests that it was not cut while the person was alive, which is inconsistent with the theory of punishment for oath breaking.



**Figure 2. The Legden Hand: Image credit:thelocal.de**

*Lunow Hand:* It is placed in a niche of an old Church built in 1250 in the village of Barnim. The hand was discovered in the 16<sup>th</sup> century and dated between 13<sup>th</sup> and 16<sup>th</sup> century. According to a local legend it represents the hand of a child who was found dead after beating his father. It is said that after the burial the hand appeared on the surface and no matter how hard they tried they could not rebury it [6].

**Group 2 (G2):** Five adult modern individuals (3 males and 2 females) obtained from the Anatomy department of Heinrich-Heine University of Düsseldorf) were analysed.

**Group 3 (G3):** Six (3 males and 3 females) randomly selected anonymized scans of individuals taken for diagnostic purposes Department of Radiology of University-Clinic, Düsseldorf were analysed.

## Methods

In order to determine the sex of the 7 hands in group 1 the following measurements from metacarpal (MTC) and phalangeal (P) bones were selected using previous studies as seen in **Table 1**:

The unknown sample of the G1 group were CT-scanned and then measured. Hand dimensions of G2 were obtained with a caliper and CT scan so that the calibration



could be verified while G3 was measured only on the 3D reconstructions of the CT scans. The CT series for sampling were recorded with a Somatom Plus 4 scanner (Siemens, Erlangen, Germany) using a tube current of 20 mA, tube voltage of 110 kV, slice thickness of 0.75 mm, and slice increment of 0.5 mm. Scans with a field of view of 250 X 250 mm<sup>2</sup> (matrix 512 X 512) were made in the coronal plane. Voxel size was 0.5 X 0.5 X 0.5 mm<sup>3</sup>.

**Table 1: List of measurements, definitions and abbreviations.**

Measurement	Abbreviation	Reference
Maximum interarticular length	ML	[7]
Anterior-posterior diameter of distal epiphysis	APDDE	[7]
Medio-lateral diameter of distal epiphysis	MLDDE	[7]
Anterior-posterior diameter of proximal epiphysis	APDPE	[7]
Mediolateral diameter of proximal epiphysis	MLDPE	[7]
Anterior-posterior midshaft diameter	apmid	[8]
Mediolateral midshaft diameter	mlmid	[8]
Maximum length M1	MaxL	[10]

## RESULTS

The lack of published osteometric data on sex determination from metacarpals for the German population creates the need for using earlier formulae. All published studies [7-10] are based on modern samples and thus are population-specific, therefore they must be carefully tested before applied to the mummified hands assumed to be of German descent. Additionally they are created using osteometric data so it must be determined whether they are applicable for measurements that are taken through CT scanning. In this regard G2 and G3 of known sex were used to test the selected formulae and make sure that they satisfied the above mentioned

criteria, so they could be applied in the CT scan measurements of the unknown hands of G1.

#### *Comparison of osteometric and virtual measurements*

Paired T-test between measurements of G2 obtained by osteometry and CT scans showed no statistically significant differences between the mean values. Differences in the measurements were smaller than 0.5mm in all cases. Therefore it was determined that CT-scan measurements could be used for sex assessment based on the published osteometric studies.

#### *Test of the applicability of published studies in Germans*

Using Scheuer and Elkinghton's [7] formulae for MTC 1 all samples (G1, G2, G3) were classified as male while for MTC 5 all samples were classified as females (Supplementary Table 1). So these two equations need to be considered with caution. Falsetti's [8] formula could not be tested for G3 because not all measurements were available in this randomly selected group of patients. The combination of the remaining equations gave correct group assessment for the vast majority of individuals from Group 2 and 3 and therefore was used in the estimation of the mummified hands. For example Individual G1.1 is a male and is classified as male in 35/50 equations used. In addition G2.1 is a female and is classified as female in all 4 equations that could be applied. G1.5 is the only individual which was misclassified as male in 28/50 equations.

#### *Prediction of sex for the unknown mummified hands.*

Sex for G1 was assessed taking into consideration the correct sex assessment of the tested formulae for the validation groups (G2 and G3) and the overall prediction using all available formulae. Table 1 shows the results of metacarpals and first proximal phalanx. As seen in Table 1 it is very likely that the unknown sample consists of five males (Münster, Erkeln, HWI 2641, Legden, Lunow), one female

(Goslar) and one of ambiguous sex (HWI 4019).

**Group 1: Prediction of sex for the unknown hands using CT measurements.** (SE: Scheuer and Elkinghton, F: Falsetti, S: Stoyanowski, Bar:Barrio).

	SE	Fal	Bar	Stojanowski							SE	Fal	Bar	Stojanowski						
				1	2	3	4	5	6	7				1	2	3	4	5	6	7
	<b>Münster</b>										<b>Erkeln</b>									
MTC1	M		M	M	M	M	M	M	M	M	M		M	F	M	M	M	M	M	M
MTC II	M	M	F	M	F	M	M	M	M	M	M	M	M	F	F	F	M	M	M	M
MTC III	M		M	F	M	F	M	M	M	M	M		M	M	M	M	M	M	M	M
MTC IV	F	F	F	F	F	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M
MTC V	F	M	M	M	M	F	M	M	M	M	F	M	M	M	F	M	M	F	M	M
p1	M										M									
mid	M										M									
	<b>HWI 2641</b>										<b>Goslar</b>									
MTC II	F	M	F	M	M	M	M	M	M	M	M	M	F	F	F	F	M	M	M	M
MTC III	M		M	F	M	M	M	M	M	M	M		M	M	F	F	M	M	M	M
MTC IV	M	M	M	M	M	M	M	M	M	M	M	M	F	M	F	F	M	M	M	M
MTC V	F	M	M	M	M	M	M	M	M	M	F	M	M	M	F	M	M	M	M	M
mid											F									
	<b>HWI 4019</b>										<b>Lunow</b>									
MTC I	M		M	F	M	F	F	F	M	M	M		M	M	M	M	M	M	M	M
MTC II	M	M	F	F	F	F	M	M	M	M	M	M	M	M	F	F	M	M	M	M
MTC III	M		F	F	F	F	F	F	F	F	M		M	M	F	M	M	M	M	M
MTC IV	M	M	M	M	M	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M
MTC V	F	M	M	F	F	F	F	F	F	F	F	M	M	M	M	M	M	M	M	M
p1	M										M									
mid	M										M									
	<b>Legden</b>																			
MTC I	M		F	F	M	F	F	F	F	F										
MTC II	M	M	M	M	M	M	M	M	M	M										
MTC III	M		M	M	F	M	M	M	M	M										
MTC IV	M	M	M	M	M	M	M	M	M	M										
MTC V	F	M	M	M	M	M	M	M	M	M										
p1	M																			
mid	M																			

## Discussion

In order to understand the social significance of the hands through history either appearing as Leibzeichen, or signs of corporal punishment, it is essential to discover the identity of the individuals. As noted above, demographic data was not available for sexing these remains. It was assumed that these individuals were of European descent, and most probably Germans, due to the geographic locations where these remains were found. Therefore, the current literature was used in order to estimate the sex of the remains, with the reservation that these studies are not based on the German population.

The selected formulae are deriving mostly from studies based on British [7], Spanish [10], European-American [8], and combined European and African American [9] samples that are expected to give diverse results when applied to individuals of different descent. A short description of their methodology and results is considered essential in order to evaluate the sex assessment that was attempted.

In a study carried out with an autopsy sample of 60 individuals of British origin six measurements from five metacarpals and the first proximal phalanx were taken and tested on 20 specimens [7]. Results provided an accuracy rate ranging from 74% to 94%, with MTC I demonstrating the highest degree of sexual dimorphism.

Falsetti (1995) also tested the measurements proposed by Scheuer and Elkington (1993), plus anteroposterior and mediolateral midshaft breadths for sexual dimorphism. In this study, the Terry collection was used and differences between European and African-Americans were tested. Accurate classification ranged from 77% for the 2<sup>nd</sup> digit, 80% for the 4<sup>th</sup> to 85% for the 5<sup>th</sup>.

Stojanowski (1999) also studied sexual dimorphism of the hand bones using the proposed six dimensions by Scheuer and Elkington (1993) and developed 35 functions with the aim of determining sex of individuals with pathological conditions and poor preservation. He studied a pooled sample of European and

1  
2  
3  
4 African-Americans all born after 1900. Sex accuracy ranged from 75-95% with MTC  
5  
6 IV providing the highest degree of sexual dimorphism. It should be stressed  
7  
8 though that the female validation sample was small and caution must be taken  
9  
10 validating the error rate for female classification.  
11

12 Barrio and coworkers (2006) also investigated metacarpal bones in a  
13  
14 contemporary Spanish population and obtained 81 to 91% classification accuracy,  
15  
16 with the highest rate for left MTC II.  
17

18 A validation study testing three of the above mentioned methods [7-9] used  
19  
20 a small sample (N=23) of recent European-American skeletons [14]. The  
21  
22 discouraging results support the theory of population specific differences in  
23  
24 osteometric values. On the other hand, a test of population-specific equations  
25  
26 deriving from a sample from the same country also gave poor classification results  
27  
28 for some formulae [15]. Other validation studies report a secular trend of declining  
29  
30 bone robusticity [16], which indicates a greater chance of misclassification in  
31  
32 females when archaeological samples are employed.  
33

34 The review of the literature clearly demonstrates that sex estimation using  
35  
36 formulae developed from different populations and chronology require special  
37  
38 methodological consideration. This is especially difficult when there are no criteria  
39  
40 for the population the unknown remains may have derived from. To simplify the  
41  
42 potential problem in this study several steps were taken.  
43

44 The sex of the hands forming G1 were estimated after a few general  
45  
46 assumptions were made deriving from the classification of G2 and G3 and the  
47  
48 literature review. Scheuer and Elkinghton's [7] formula for metacarpal V classified  
49  
50 all samples (G1-3) as female probably due to population differences or typos in the  
51  
52 equation; hence it was not used for sex estimation. Additionally, Equation 1 gave  
53  
54 male values for all samples in the same study; thus it was not taken into account in  
55  
56 samples that were indicating a female value using other formulae. In contrast  
57  
58 Barrio's [10] equations seem to have the best accuracy rate in correct classification  
59  
60 for G2 and G3, while Stojanowski [9] predicted more accurately than expected in a  
61  
62  
63  
64  
65

validation sample of another study [14]. It must be stressed that these remarks don't represent a testing of accuracy of the other studies but to find a logical way to evaluate the complex results produced in table 1 for the specific sample under study.

In this regard, one can suggest that G1 consists most likely of 5 male and 1 female individuals as seen in Table 1. Among them the Goslar hand represents a rather controversial case that is difficult to classify either way (see table 1). It could be suggested that that it is more likely to be a female individual based on the appearance of female values in the formulae produced by Barrio [10] and Stojanowski [9] that seem to be more accurate in classifying females, and on the expected misclassification of females as males in archaeological samples as noted above [16]. Naturally this assumption is expressed with reservation due to the diversity of the predicted values for that case.

Misclassification of sex in these remains enhances the danger of misquoting the social and legal aspects of life during Middle Ages. For example, if all *Leibzeichen* are classified as male, one could assume that only the male hands are brought to court. Consequently, in order to reconstruct the archaeological scene and interpret these findings a DNA-investigation along with radiocarbon dating is needed.

In conclusion, estimation of sex from metacarpals using CT scan measurements is a novelty and requires a well calibrated population-specific sample, especially when applied to archaeological and mummified specimens. Bearing this in mind, it would be preferable to create a database of known sex in the medieval German population in order to assess sex for the mummified hands of G1 with better accuracy. Clearly the need for further investigation and DNA analysis of these hands to verify the preliminary morphometric sex assessment.

## Acknowledgments

EK would like to thank Dr. Peter Pieper for allowing access to the CT scans of the

1  
2  
3  
4 mummified hands and sharing his knowledge and experience in the archaeological  
5 interpretation of these findings. Thanks to the Department of Radiology of  
6 University-Clinic, Düsseldorf, Germany for granting access to anonymized CT-  
7 scans of patients and for allowing the use of 3D software. Special thanks to  
8 Caroline Lill for the English review of the manuscript.  
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Supplementary table S1. Sex estimates using all equations for G1, G2 and the unknown G3.

		MTC I										MTC II										MTC III										MTC IV											MTC V										p1	mid		
No	sex	SE	S1	S2	S3	S4	S5	S6	S7	Bar	SE	Fal	S1	S2	S3	S4	S5	S6	S7	Bar	SE	S1	S2	S3	S4	S5	S6	S7	Bar	SE	Fal	S1	S2	S3	S4	S5	S6	S7	Bar	SE	SE	F	M													
G1.1	1	M	F	M	F	F	F	F	F	F	M	M	M	F	M	F	F	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	15	35												
G1.2	1			M							F	M	F	F	F	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	6	36												
G1.3	1	M	F	M	M	M	M	M	M	F	F	M	F	M	F	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	7	43												
G1.4	2	M	F	M	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	M	F	F	F	F	F	F	F	F	M	F	F	F	F	F	F	F	F	F	F	F	F	46	4												
G1.5	2	M	M	M	F	F	M	M	F	M	F	F	F	F	F	M	M	M	M	M	M	F	M	F	M	F	F	F	F	F	M	F	M	M	F	M	M	M	M	F	F	M	F	22	28											
G2.1	2												F							F		F							F														4	0												
G2.2	2	M	M	M	M	F	F	F	F				F							F		F							F				F										10	4												
G2.3	2			M										F									F										F								M			5	2											
G2.4	1		M										M							M		M							M				M											0	7											
G2.5	1		M										M							M		M							M				M											0	7											
G2.6	1	M	M	M	M	M	M	M	M	M			M							M		M							M				M								M			0	17											
Munster	UN	M	M	M	M	M	M	M	M	F	M	M	M	F	M	M	M	M	M	F	M	F	M	F	M	M	M	M	M	M	F	F	F	F	F	M	M	M	M	M	M	M	M	12	38											
Erkeln	UN	M	F	M	M	M	M	M	M	M	M	M	F	F	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	7	43											
hwi 4019	UN	M	F		F	F	F	M	M	M	M	M	F	F	F	F	M	M	M	F	M	F	F	F	F	F	F		M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	23	24										
hwi 2641	UN										F	M	M	M	M	M	M	M	M	F	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M			4	34											
Gosslar	UN										M	M	F	F	F	M	M	M	M	F	M	M	F	F	M	M	M	M	M	M	M	M	M	F	F	M	M	M	M	M	F			11	27											
Legden	UN	M	F	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	4	46											
Lunov	UN	M		M	M	M	M	M	M	M	M	M	M	F	F	M	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M	M	F	F	M	M	M	M	F			M	M	5	45											

SE

Scheuer and Elkington

Fal

Falsetti

S

Stoyanowski

Bar

Barrio